The importance of critical experiences and periods in teaching-learning processes throughout the lifespan

Ernesto Mascarell Perez
Independent Researcher
mascarell1960@hotmail.com

Abstract

Traditional teaching-learning models have systematically ignored the influence of hormonal dynamics, critical experiences, and maturational variability, furthermore restricting their analysis to formal education (childhood and adolescence). This article expands the framework to the entire lifespan, proposing four dimensions of human development – Power, Knowledge, Will, and Belief – which recursively feed back from infancy to old age. It analyzes how critical hormonal periods (prenatal, minipuberty, adrenarche, puberty, pregnancy, perimenopause, andropause, aging) modulate each dimension, and how the asynchrony between chronological and biological age influences human development processes. The impact of critical psychosocial experiences (bonds, losses, abuse, successes, failures, job changes, retirement) on each dimension is also examined. The neuroendocrine mechanisms underlying these effects are explored in depth, including the role of hormones such as testosterone, estrogens, DHEA, cortisol, oxytocin, and melatonin. The article concludes with a summary table of concrete proposals for designing educational interventions sensitive to recursivity and maturational variability at all life stages.

Keywords: critical hormonal periods, maturational asynchrony, power, knowledge, will, belief, recursivity, lifelong learning, continuing education, aging, educational neuroendocrinology.

---

1. Introduction

The search for effective and equitable education has led to the consideration of multiple variables: learning styles, emotional intelligence, socioeconomic context, etc. However, a fundamental biological factor has been systematically ignored: the person's endocrine status and their history of critical experiences.

Hormones not only regulate sexual and metabolic development; they act as neuromodulators that alter synaptic plasticity, brain connectivity, and stress response. During certain critical periods (prenatal, minipuberty, adrenarche, puberty, pregnancy, perimenopause, andropause, aging), these actions are especially profound and long-lasting, exerting either permanent organizing effects or temporary activating effects.

Furthermore, human development is recursive: each experience modifies the structure that will generate subsequent experiences. There is a fundamental asynchrony between chronological age (marked by the calendar) and biological age (the degree of hormonal, neurological, physical, and motor maturation or involution). Two individuals with the same birth date can have very different maturational trajectories throughout their entire lives.

To provide coherence to this framework across the entire lifespan, we propose four dimensions that capture the recursive dynamics of development: Power, Knowledge, Will, and Belief. Each of these is modulated by critical hormonal periods and affected by maturational asynchrony, from infancy to old age. The objective of this article is to analyze these interactions, detail the underlying neuroendocrine mechanisms, and derive concrete educational proposals for all stages of life.

---

2. Critical Hormonal Periods Throughout Life: Neuroendocrine Foundations

The main critical periods throughout the entire lifespan are as follows. Contrary to common belief, these periods not only affect cognition and emotion but also have direct consequences on physical power, motivation, and beliefs.

2.1 Prenatal Period and Minipuberty (0-6 months)

During fetal life, testosterone (in male fetuses) and, to a lesser extent, estrogens organize hypothalamic and cortical circuits that will influence visuospatial ability, exploratory tendency, and stress reactivity. In minipuberty (the first 6 months postpartum), there is a peak in luteinizing hormone (LH) and follicle-stimulating hormone (FSH) that consolidates hemispheric dominance and the sensitivity of glucocorticoid receptors.

2.2 Adrenarche (6-8 years)

The adrenal gland increases the secretion of DHEA (dehydroepiandrosterone), a weak androgen that acts on the hippocampus and prefrontal cortex. DHEA improves episodic memory (recalling facts and events) and selective attention. It

also modulates the stress response, acting as a neuroprotectant. **Educational window:** Ideal for introducing factual learning (history, geography, natural sciences) and for working on basic emotional regulation. It is an excellent time to consolidate the Knowledge → Belief loop.

2.3 Puberty (8-15 years)

This is the most critical period for secondary education. Estrogens (in girls) and testosterone (in boys) enhance the plasticity of the prefrontal cortex and hippocampus, improving abstract reasoning and long-term memory. However, they also increase amygdala reactivity (intense emotions, greater sensitivity to social rejection) and sensation seeking (dopamine). Learning is affected by several specific hormonal factors:

- **Menstrual cycle in girls:** Estrogens in the follicular phase improve verbal memory and fluency; progesterone in the luteal phase can slow word retrieval and increase irritability. Education should allow adjustments in verbal memory tasks according to the phase and not penalize symptoms.
- **Melatonin circadian phase delay:** In puberty, melatonin secretion is delayed, causing adolescents to be naturally more alert in the afternoon and have difficulty sleeping early. Morning school schedules contradict this biology, reducing attention and performance.
- **Sensitivity to social rejection:** Oxytocin and vasopressin modulate bond formation; cortisol and dopamine amplify the response to rejection. Public praise or criticism can have disproportionate effects on motivation and self-esteem.

2.4 Pregnancy

During pregnancy, elevated levels of estrogens and progesterone reorganize the maternal brain. A transient decline in verbal memory ("baby brain") and an increase in learning stimuli related to infant care are common. There is also greater social plasticity. **Educational adaptation:** In continuing education and university, external memory supports (class recordings, summaries, lists) and schedule flexibility to accommodate fatigue should be offered.

2.5 Perimenopause (40-55 years)

The decline in estrogens and progesterone affects verbal memory, executive function (planning, inhibition), and emotional regulation. "Brain fog" and increased irritability may appear. Hormone replacement therapy can mitigate these effects. **Educational implication:** Hormonal psychoeducation to explain that forgetfulness is not "premature aging" but reversible endocrine changes. Offer memory supports and reduce the pressure for speed.

2.6 Andropause (from 40-50 years)

Gradual decline in testosterone (1-2% per year). It affects muscle mass and strength (physical power), motivation (will), spatial memory, and mood. It is not as abrupt as perimenopause, but its cumulative effects are significant. **Intervention:** Compensatory strength training, psychoeducation, and design of meaningful goals (purpose, legacy).

2.7 Advanced Aging (>70 years)

General hormonal decline: drop in DHEA, melatonin, gonadal hormones, and insulin-like growth factor (IGF-1). Synaptic plasticity is reduced (less protein synthesis and brain-derived neurotrophic factor, BDNF) and vulnerability to stress increases (elevated cortisol). However, semantic knowledge and procedural wisdom are maintained or even improved. **Educational key:** Use slow, repetitive, and multisensory methods; leverage peer learning and legacy.

These periods do not occur at the same chronological age in all individuals. Hence the importance of asynchrony at all stages, which is addressed in section 3.5.

---

3. The Four Dimensions of Human Development: Power, Knowledge, Will, Belief

3.1 Dimension Power (including physical power)

Definition: Power is the real capacity to act, to decide, to access resources, and to influence the environment. It includes physical power: strength, endurance, speed, and coordination. Maturational asynchrony generates enormous differences in physical power within the same chronological age. In puberty, the rapid growth spurt produces pubertal awkwardness (temporary loss of coordination due to uneven growth of bones and tendons) that reduces motor power. In adulthood, differential aging (accelerated or slow) determines the loss or maintenance of functional power.

3.2 Dimension Knowledge

Definition: Knowledge, skills, cognitive strategies. Following Gopnik (2009, 2016), learning is a process of constructing probabilistic causal models, not of rigid stages in the Piagetian style. Young children are "active causal explainers" who learn through exploration and intuitive statistics. The capacity for abstraction does not emerge suddenly, but gradually and asynchronously across

domains. Asynchrony affects the rate of acquisition of abstract reasoning, working memory, and processing speed. In perimenopause and aging, the decline in verbal or fluid memory is highly variable among individuals.

3.3 Dimension Will

Definition: Motivation, goals, interests, desires. Puberty intensifies the will (novelty seeking, sensitivity to rejection) due to the interaction between dopamine, testosterone/estrogens, and oxytocin. In adulthood, the will is reoriented towards achievement, legacy, or the maintenance of autonomy. Accelerated asynchrony (premature aging) can reduce the will due to fatigue or chronic pain.

3.4 Dimension Belief

Definition: Beliefs about oneself (self-efficacy, self-concept), about the world, and about the value of learning. Experiences of failure due to maturational mismatch (e.g., a late-maturing child in a higher-grade class) can damage self-concept and create learned helplessness. In adulthood, belief can be reinforced by achievement or eroded by age-related discrimination. The recursivity between Belief and the other dimensions is fundamental: if a person believes they cannot learn (Belief), they will not make an effort (Will), will not practice (Knowledge), and will lose social influence (Power).

3.5 The Asynchrony Between Chronological and Biological Age: Graphic Representation Throughout the Lifespan

Biological age is determined by the interaction of genetic, nutritional, endocrine (leptin, kisspeptin, GnRH), psychological (chronic stress accelerates puberty), and environmental factors (endocrine disruptors). In a single class of 25 students aged 12 chronologically, we can find children with a biological age of 10 (prepubertal), 12-13 (in full puberty), and 14-15 (postpubertal).

Figure 1. Asynchrony between chronological age and biological age throughout the human lifespan.

In the original graph, it is also observed that at 12 chronological years, the band covers a range of 4 years – from 10 to 14 biological years – and at 50 chronological years, the band covers up to 20 years – from 40 to 60 biological years, demonstrating that asynchrony is cumulative and widens with age.

First Critical Milestone: Childhood and Adolescence (12 chronological years) – Range of 4 years. Consequences in the four dimensions:

- **Power:** Prepubertal (low strength, dependency), mid-pubertal (awkwardness due to growth spurt), postpubertal (adult strength).

- **Knowledge:** Emergent abstract reasoning → vulnerable acceleration → optimization.
- **Will:** From play and adult approval → peak susceptibility to social rejection → long-term goals.
- **Belief:** Self-concept based on own progress → lability due to social comparison → internal consolidation.

Second Critical Milestone: Adulthood and Aging (50 chronological years) – Range of 20 years.

- **Power:** Slow aging (preserved functional reserve) vs. accelerated (sarcopenia, frailty).
- **Knowledge:** Decline of fluid intelligence and working memory faster in accelerated asynchrony.
- **Will and Belief:** Perception of premature physical loss generates adaptive stress and damages self-efficacy.

Pedagogical and Social Implication: Grouping by chronological age assumes a nonexistent homogeneity; it condemns late-maturing individuals to failure and early-maturing ones to boredom. Assessing health, work productivity, or retirement solely by chronological age is a structural bias. Personalization of medicine, occupational prevention, and active aging is required.

---

4. Critical Psychosocial Experiences, Hormones, and Recursivity in the Four Dimensions

Critical experiences (bonds, ruptures, abuse, successes, failures, job changes, retirement, loss of loved ones, illnesses) do not act on a neutral system, but on each dimension differentially and with differing impacts at each life stage. Furthermore, they are recursive: a change in one dimension propagates to the others.

4.1 Secure Bonds and Ruptures

Oxytocin released in secure relationships reduces cortisol and facilitates hippocampal plasticity (better explicit learning). A romantic breakup during puberty elevates chronic cortisol, which inhibits long-term potentiation (LTP) and impairs memory consolidation. Schools should offer psychological support and not trivialize adolescent grief.

4.2 Abuse and Trauma

Child maltreatment alters the hypothalamic-pituitary-adrenal (HPA) axis, reducing hippocampal volume (contextual memory) and increasing that of the amygdala (hypervigilance). These students have difficulty learning that a context is safe and have working memory failures. Punitive methodologies or public humiliation are particularly damaging. Low-threat environments, predictable routines, and explicit emotional regulation strategies are required.

4.3 Repeated Success and Failure

Success releases dopamine and increases testosterone/estrogens, creating a virtuous cycle of motivation and learning improvement. Chronic failure elevates anticipatory cortisol (before an exam) and reduces D2 dopamine receptors, generating learned helplessness and avoidance behaviors. Pedagogy should restructure evaluation so that error is informative and non-threatening, guaranteeing frequent micro-successes.

4.4 Examples of Recursivity (Involutive and Evolutive Loops)

Involutive Loop (50-year-old adult):

A woman in perimenopause begins to notice forgetfulness (loss of verbal Knowledge). She attributes these lapses to "I'm already older, I'm becoming stupid" (negative Belief). She stops wanting to sign up for continuing education courses (low Will). Her boss, seeing her less motivated, removes important projects from her (low Power). With less practice, her cognitive skills actually worsen (low Knowledge). The loop closes and intensifies.

Evolutive Loop (60-year-old adult):

A man in andropause notices less strength (low physical Power). Instead of giving up, he looks for a personal trainer who adapts exercises for him (Power of decision). He improves his physical fitness, gains strength (recovered physical Power). This makes him believe he can still improve other abilities (positive Belief). He signs up for a computer course, learns (new Knowledge). His general self-efficacy rises, he wants more challenges (high Will). Virtuous loop.

Critical experiences amplify these loops: job loss at 55 can damage Belief, Power, and Will; loss of a partner in old age can reduce social Power, but also open up a new Will for learning if managed well.

4.5 Recursivity as an Antidote to Determinism

It is often thought that critical periods are "closing windows." However, recursivity shows that the system never stops feeding back. What changes is the speed and cost of changes, not the possibility. An attention deficit due to childhood trauma can be partially reversed in adulthood through low-threat

environments and emotional regulation exercises. An adolescent with chronic school failure can, through a project where real power is granted, experience success that breaks the involutive loop.

---

5. Concrete Educational Proposals by Dimension Throughout the Lifespan

Below, the proposals from the original article are expanded, incorporating specific adaptations for each critical period and actions to enhance recursivity.

5.1 Proposals for the Power Dimension (Expanded)

- **Childhood (6-12 years):** Recognize maturational asynchrony. In physical education, use benchmarks by biological age (Tanner stages) or growth percentiles, not chronological age. Do not label the child in the middle of a growth spurt as "clumsy." Adapt fine motor tasks (writing, drawing) during the rapid growth spurt. Explain pubertal awkwardness to students and families.
- **Adolescence (12-18 years):** For early-maturing students: roles of physical responsibility (helping move materials, leading teams). For late-maturing students: avoid public humiliation, use activities where strength is not the only factor (coordination, strategy). Offer proprioceptive training.
- **Middle Adulthood (35-55 years):** In perimenopause and andropause, adapt training tasks that require physical strength or prolonged endurance. Compensatory training (gentle strength exercises, proprioception to prevent falls).
- **Late Adulthood (55-70 years):** Design accessible environments (ramps, armchairs). Teach the use of technical aids (canes, hearing aids) without stigma.
- **Old Age (>70 years):** Fully accessible environments, learning assistive technologies, intergenerational programs.

5.2 Proposals for the Knowledge Dimension (Expanded)

- **Childhood:** Respect abstraction rhythms (Gopnik's view: learning through causal models). Use exploration and experiments. Assess by individual progress.
- **Adolescence:** Take advantage of the window of maximum plasticity for abstract reasoning, but protect from stress (chronic cortisol damages the hippocampus). Teach metacognition. For girls, consider menstrual cycle phases (verbal memory supports in the luteal phase).

- **Young Adulthood (20-35 years):** In pregnancy, offer external memory supports (class recordings, summaries). Do not confuse normal forgetfulness with "permanent decline."
- **Middle Adulthood (35-55 years):** Recognize that processing speed may decline slightly, but semantic knowledge increases. Use problem-based learning.
- **Late Adulthood (55-70 years):** Use methods that do not depend on speed (self-paced learning). Maintenance of procedural memory.
- **Old Age (>70 years):** Very flexible pace, multiple formats, teaching compensatory strategies (agendas, alarms, smartphones). Do not assume they "can no longer learn."

5.3 Proposals for the Will Dimension (Expanded)

- **Childhood:** Motivate with immediate rewards, play, and natural curiosity. Do not force premature social competition.
- **Adolescence:** Avoid public humiliation (maximum sensitivity to rejection). Offer real autonomy (choose topics, methodology, evaluation). Channel sensation seeking towards controlled intellectual and physical challenges.
- **Young Adulthood:** Connect training with tangible goals (promotion, career change). In pregnancy, recognize that fatigue temporarily reduces motivation; schedule flexibility.
- **Middle Adulthood:** Apathy may have a hormonal cause (perimenopause, andropause); do not label it as "lack of motivation" without exploration. Offer purpose and legacy goals.
- **Late Adulthood and Old Age:** Non-formal education without evaluative pressure (workshops, reading clubs, senior universities). Intergenerational programs where seniors teach something (they recover the will by feeling useful).

5.4 Proposals for the Belief Dimension (Expanded)

- **Childhood:** Praise effort and strategy (growth mindset). Avoid public comparisons. Explain that late maturation is not inferiority. Design guaranteed micro-successes for late-maturing children. Early intervention to prevent learned helplessness.
- **Adolescence:** Private, formative, and progress-based assessment. Work explicitly on growth mindset. Normalize error as a source of information.
- **Young Adulthood:** Do not confuse pregnancy forgetfulness with loss of capacity. Psychoeducation: "it's hormonal and temporary."
- **Middle Adulthood:** Hormonal psychoeducation: explain that forgetfulness, fatigue, or apathy in perimenopause/andropause are

endocrine changes, not "aging" or "irreversible decline." Guaranteed micro-successes.

- **Late Adulthood and Old Age:** Combat the belief "I can no longer learn" with testimonials from older people who have learned (modeling effect). Show examples of brain plasticity in old age. Interventions with very evident early micro-successes. Avoid language that infantilizes or assumes incapacity.

5.5 Final Summary Table: Educational Proposals by Life Stage and Dimension (Integrated)

Life Stage	Power	Knowledge	Will	Belief
Childhood (6-12)	Benchmarks by biological age; don't label clumsiness; adapt fine motor skills.	Respect abstraction rhythms (Gopnik); assess by progress.	Immediate rewards; play; don't force social competition.	Praise effort; avoid comparisons; explain late maturation. Early intervention.
Adolescence (12-18)	Explain pubertal awkwardness; cooperative roles for early maturers; avoid humiliating late maturers.	Take advantage of plasticity, protect from stress; teach metacognition; consider menstrual cycle.	Authentic projects; avoid public humiliation; give real autonomy.	Private assessment; growth mindset explicitly.
Young Adulthood (20-35)	Pregnancy: physical adaptations, rest breaks; maintain light exercise.	Take advantage of peak skills; pregnancy: external memory supports.	Connect with tangible goals; recognize pregnancy fatigue.	Don't confuse pregnancy forgetfulness with loss; micro-successes.

Life Stage	Power	Knowledge	Will	Belief
Middle Adulthood (35-55)	Perimenopause/ andropause: adapt physical tasks; compensatory training.	Problem-based learning; verbal memory supports.	Apathy may be hormonal; meaningful goals (purpose, legacy).	Hormonal psychoeducation; micro-successes; don't label by age.
Late Adulthood (55-70)	Accessible environments; teach technical aids without stigma.	Use non-speed-dependent methods; leverage wisdom and procedural memory.	Non-formal education; intergenerational programs.	Combat belief "I can no longer"; examples of older learners.
Old Age (>70)	Fully accessible environments; assistive technologies.	Very flexible pace; compensatory strategies (agendas, alarms).	Education based on pleasure, legacy, social connection.	Early micro-successes; peer testimonials; avoid infantilization.

---

6. Discussion

The graph presented and its structural analysis demonstrate that the asynchrony between chronological and biological age is not a minor phenomenon restricted to childhood, but a fundamental property of human development that accumulates throughout life. The variability band progressively widens, reaching a range of 20 years in middle adulthood. This has profound implications for education in a broad sense: from school to continuing education, professional retraining, occupational health, and active aging.

The recursivity of the four dimensions (Power, Knowledge, Will, Belief) implies that an educational intervention that ignores asynchrony can generate lasting

involutive loops, while an intervention sensitive to the actual biological age can trigger virtuous spirals of learning and well-being. The summary table provides concrete guidance for each life stage and each dimension.

Limitations: This article is an integrative theoretical framework. Longitudinal empirical studies are needed that measure biological age (using hormonal indicators, growth curves, Tanner stages) and the four dimensions simultaneously, as well as controlled interventions that evaluate the impact of the proposed adaptations.

---

7. Conclusions

Teaching-learning throughout the lifespan cannot continue to ignore the asynchrony between chronological and biological age. The four dimensions – Power, Knowledge, Will, and Belief – recursively feed back from infancy to old age, modulated by critical hormonal periods and life experiences. The proposed graph visualizes how the band of maturational variability widens with age, generating in adulthood ranges of up to 20 years of biological difference for the same chronological age.

An educational system (understood as formal, continuing, vocational, and social training) that aims to be inclusive and effective must:

1. Recognize individual variability in maturation and aging in its four dimensions.
2. Design specific interventions for each life stage (puberty, pregnancy, perimenopause, andropause, retirement, etc.).
3. Train educators (of children, youth, adults, and seniors) in lifespan neuroendocrinology, in managing asynchrony, and in recursive dynamics.
4. Use recursivity to interrupt involutive loops and enhance evolutive ones.
5. Design methodologies, evaluations, and learning environments adapted to the real biological age, not just the chronological one.

Applied educational neuroendocrinology across the entire lifespan is not a fad: it is an ethical and scientific necessity for learning to be truly lifelong, inclusive, and empowering at all ages.

---

8. References

1. Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freeman.
2. Blakemore, S. J. (2012). Imaging brain development: The adolescent brain. *NeuroImage*, 61(2), 397-406.
3. Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.
4. Gopnik, A. (2009). *El bebé científico* [The Scientific Baby]. Oxford University Press.
5. Gopnik, A. (2016). *El niño filósofo* [The Philosophical Baby]. Taurus.
6. Hensch, T. K. (2004). Critical period regulation. *Annual Review of Neuroscience*, 27, 549-579.
7. Lupien, S. J., et al. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience*, 10(6), 434-445.
8. Park, D. C., & Bischof, G. N. (2013). The aging mind: Neuroplasticity in response to cognitive training. *Dialogues in Clinical Neuroscience*, 15(1), 109-119.
9. Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory*. Guilford Press.
10. Schaie, K. W. (2013). *Developmental influences on adult intelligence*. Oxford University Press.
11. Shirtcliff, E. A., et al. (2009). Neurobiology of pubertal timing and its consequences. *Hormones and Behavior*, 55(5), 597-608.
12. Tanner, J. M. (1962). *Growth at adolescence*. Blackwell Scientific Publications.
13. Von Foerster, H. (2003). *Understanding understanding*. Springer.